Red Rover(s), Red Rover(s):
How Pathfinder and MER Experience Will Feed Forward to Enable and Enhance MSL Science

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with incredible support from hundreds of colleagues on the MPF, MER/Athena and MSL Science Teams and the JPL MER Engineering & Operations teams

OUTLINE

- MPF, MER, MSL Review/Reminders:
  - Mission, Science, and Operations Goals
  - Instrument and Measurement Capabilities
  - Major Science Results so far...
- Some lessons learned* from MPF and MER with implications for MSL...

*non-exhaustive, science focused...

Mars Pathfinder Rover Mission Goal

- Demonstrate the mobility and usefulness of a microrover on the surface of Mars
- Primarily a technology demo mission

Mars Pathfinder Project

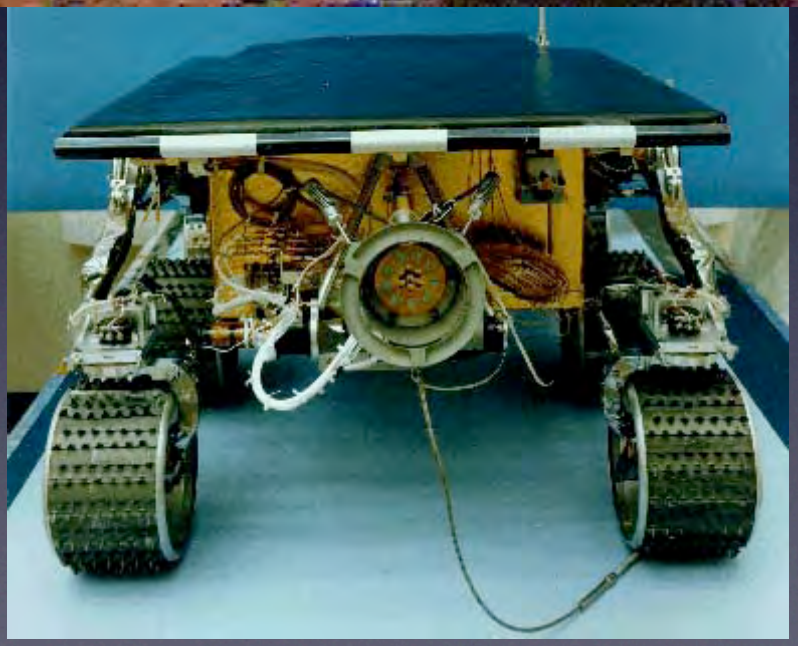
JPL

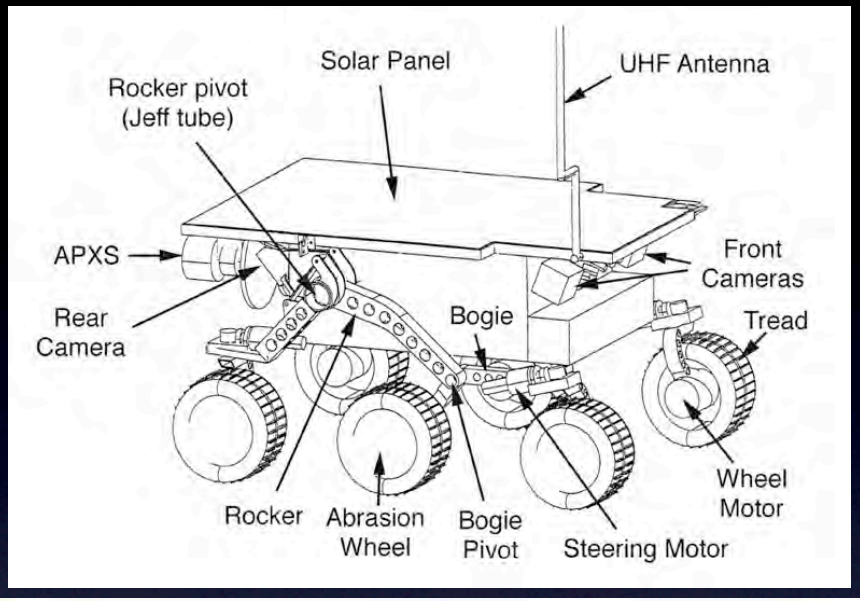
Science Objectives

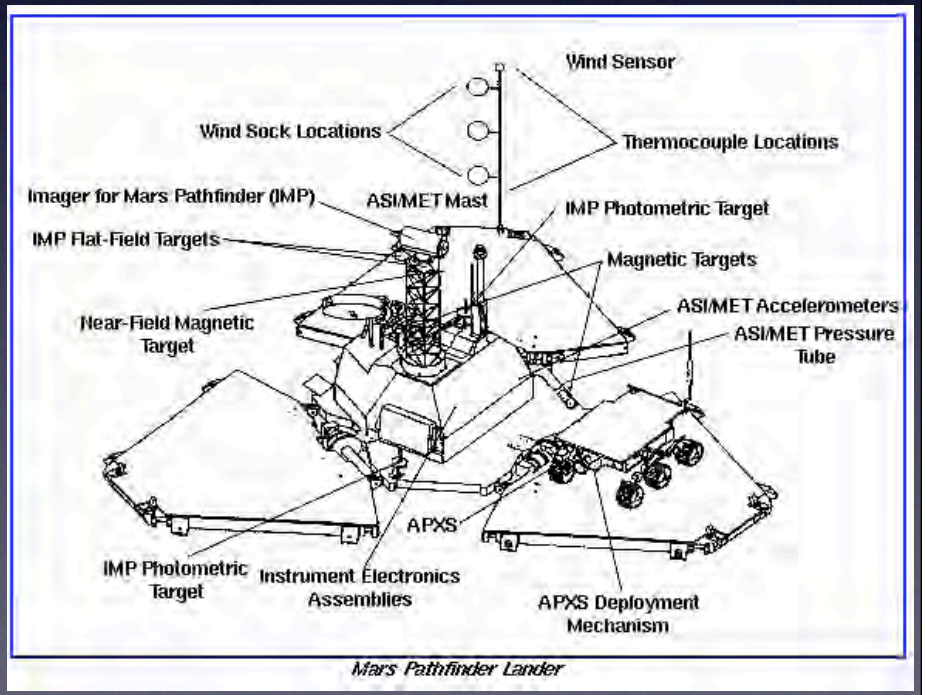
- Surface morphology and geology at meter scale
- Surface Mineralogy and Elemental Composition of rocks, soil, and surface materials
- Magnetic properties and soil mechanics of dust
- Atmosphericstructure as well as diurnal and seasonal meteorological variations
- Rotational and orbital dynamics of Mars

MPF
R.Anderson

Sojourner Science Payload







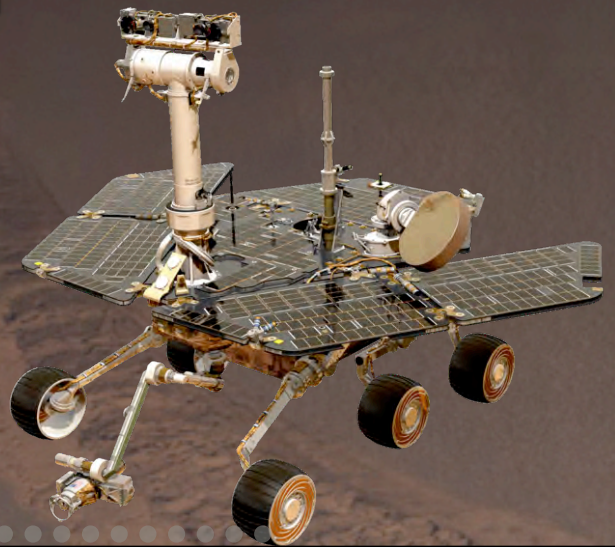
Mars Pathfinder Lander

Mars Pathfinder Surface Science (and Rover) Highlights

- Geology of the landing site shows strong evidence for fluvial processes (rock size distribution, ridges and troughs, imbrication, distant streamlined islands)
- Geology of the landing site shows substantial evidence for aeolian processes (duneforms, ripples, ventifacts)
- Chemistry of the rocks is substantially different from the chemistry of the SNC meteorites (possibly andesitic or basaltic andesite, *if volcanic*)
- Chemistry of the aeolian soils is strikingly similar to that measured by Viking, but possible locally-derived soils show significant variability
- Mineralogy of the soils is spectrally dominated by poorly crystalline or nanophase iron oxides, implying substantial oxidation/weathering
- Martian dust is strongly magnetic, and may be composed of micron-sized composite particles containing maghemite (gamma-Fe_2O_3), possibly formed via precipitation from solution.
- Refined moment of inertia of Mars allows new constraints on core radius: 1300 to 2000 km

Mars Exploration Rover Mission Goal

- Spirit and Opportunity's goal is to determine the aqueous, climatic, and geologic history of sites on Mars where conditions may have been favorable to the preservation of evidence of prebiotic or biotic processes
- Was Mars habitable?

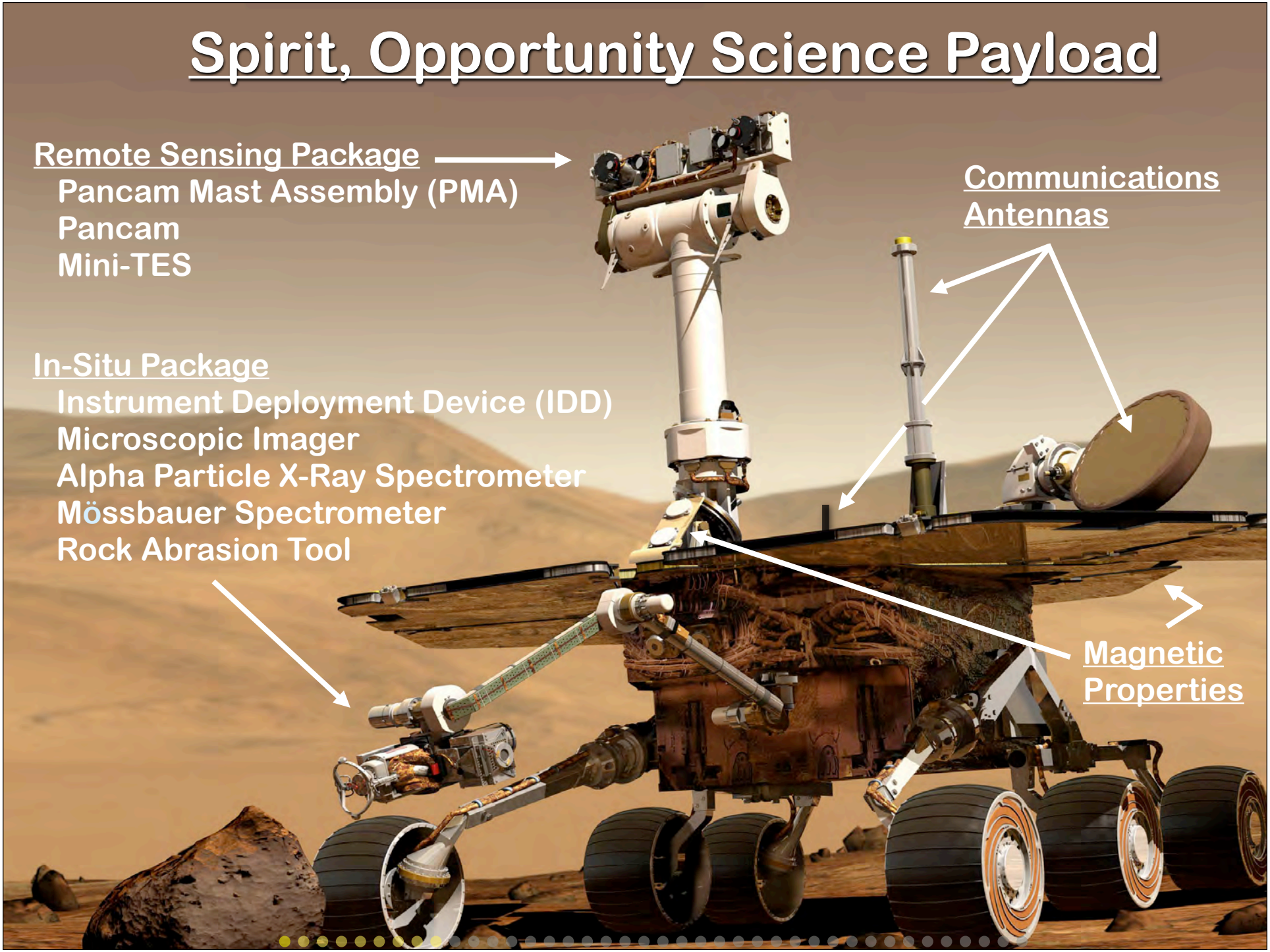


Mars Exploration Rover Science Goals

Athena Mars Rover Payload

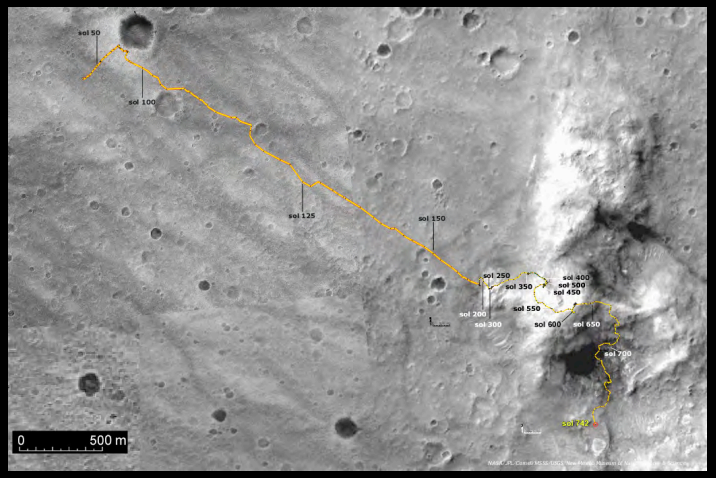
- Search for and **characterize the mineralogy, morphology, and textures of a variety of rocks and soils** that hold clues to past water activity. In particular, samples sought will include those that have **minerals deposited by water-related processes such as precipitation, evaporation, sedimentary cementation, or hydrothermal activity**.
- Determine the distribution and **composition of minerals, rocks, and soils surrounding the landing sites**.
- Determine what **geologic processes** have shaped the local terrain and influenced the chemistry. Such processes could include water or wind erosion, sedimentation, hydrothermal mechanisms, volcanism, and cratering.
- Perform **"ground truth"** -- calibration and validation -- of surface observations made by Mars orbiter instruments. This will help determine the accuracy and effectiveness of various instruments that survey Martian geology from orbit.
- Search for geological clues to the **environmental conditions that existed when liquid water was present**. Assess whether those environments were conducive to life.

Spirit, Opportunity Science Payload

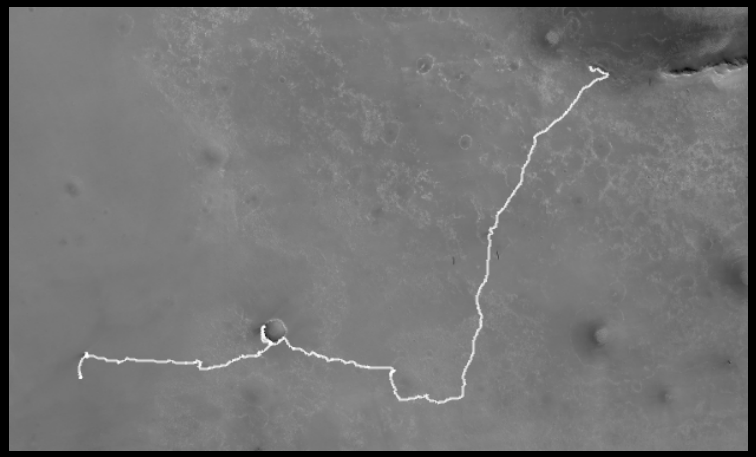


For MER, mobility is a critical science asset

Spirit, sols 1-90



Opportunity, sols 1-90



MER Surface Science Highlights

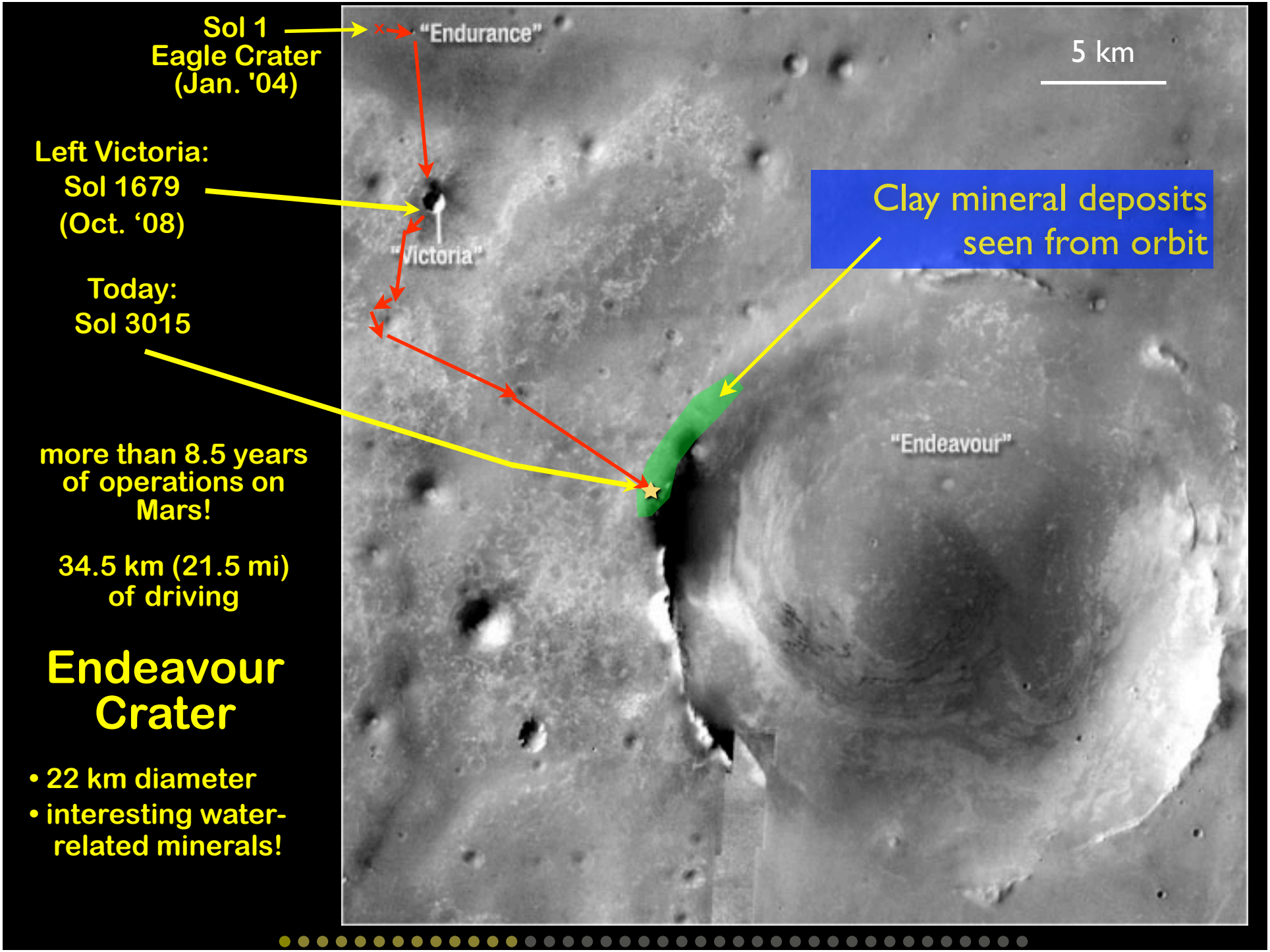
Spirit/Gusev Crater

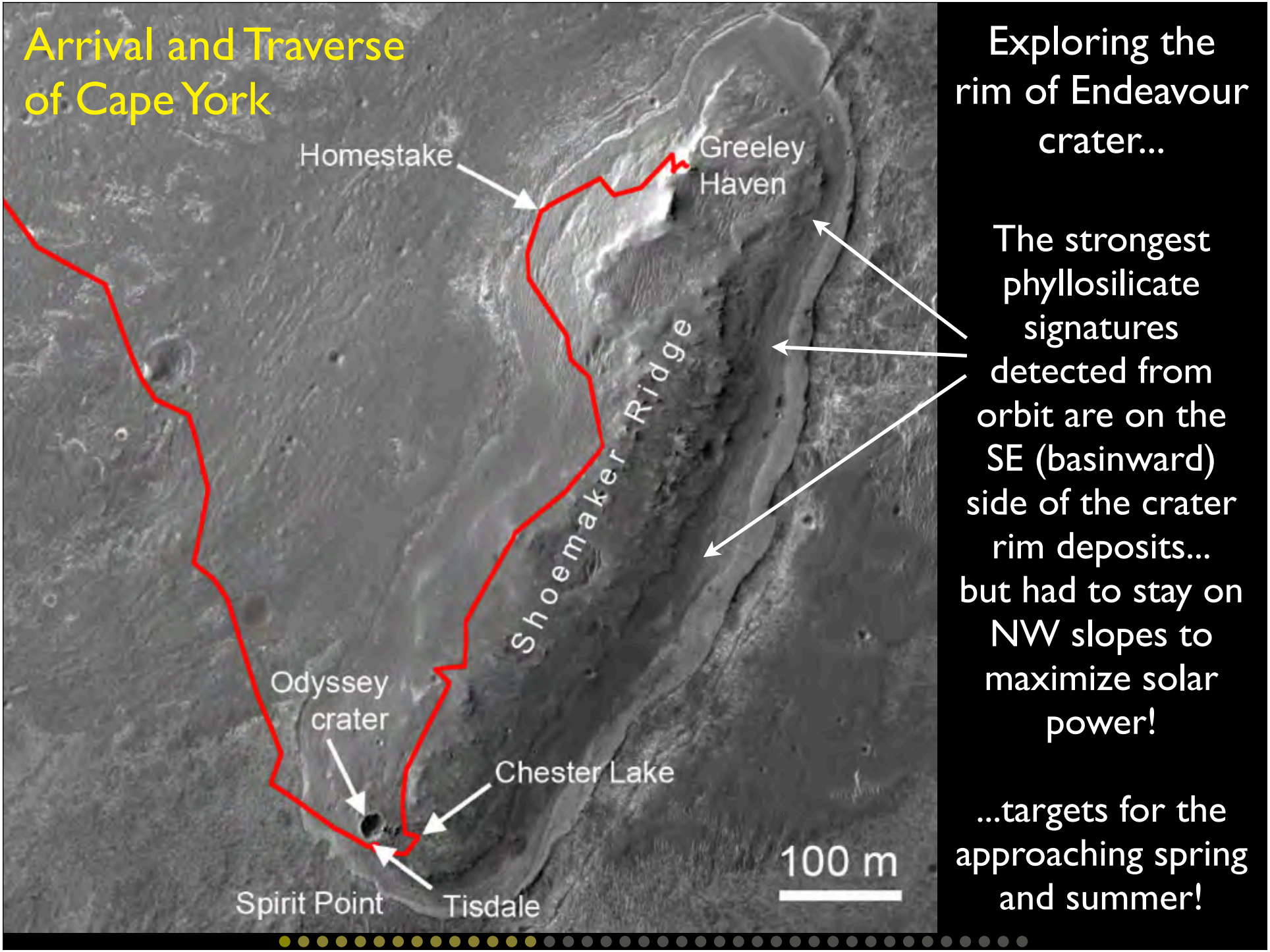
- 7730 meters of traverse over 2210 sols
- Abundant olivine-rich basalts in Gusev plains: low water:rock
- Significant textural and lithologic (primarily basaltic) diversity in Columbia Hills rocks, some as float, some as outcrop
- Discovered hematite, goethite, and carbonates in rocks and high Mg, Fe, S, Cl, Br in some soils in and around the Columbia Hills: higher water:rock alteration than plains
- Layered volcaniclastic sediments, scoria, and high S, Si subsurface soils consistent with hydrothermal origin of Home Plate: higher water: rock alteration still

MER Surface Science Highlights

Opportunity/Meridiani Planum

- 34,525 meters of traverse over 3015 sols (so far...)
- Detailed investigations conducted at a series of impact craters: Eagle, Endurance, Victoria, Endeavour (ongoing)
- Plains and excavated/exposed subsurface contain basaltic sand and S, Cl, Br-rich minerals, including jarosite and hematite, the latter interpreted to be concretions precipitated from water-saturated rocks
- Layered, laminated, and cross-bedded textures on some outcrop rocks support a shallow surface water hypothesis
- Evidence for rinds and mineral-filled veins, including the recent discovery of gypsum, imply extensive aqueous transport, alteration, and regional variations in water pH

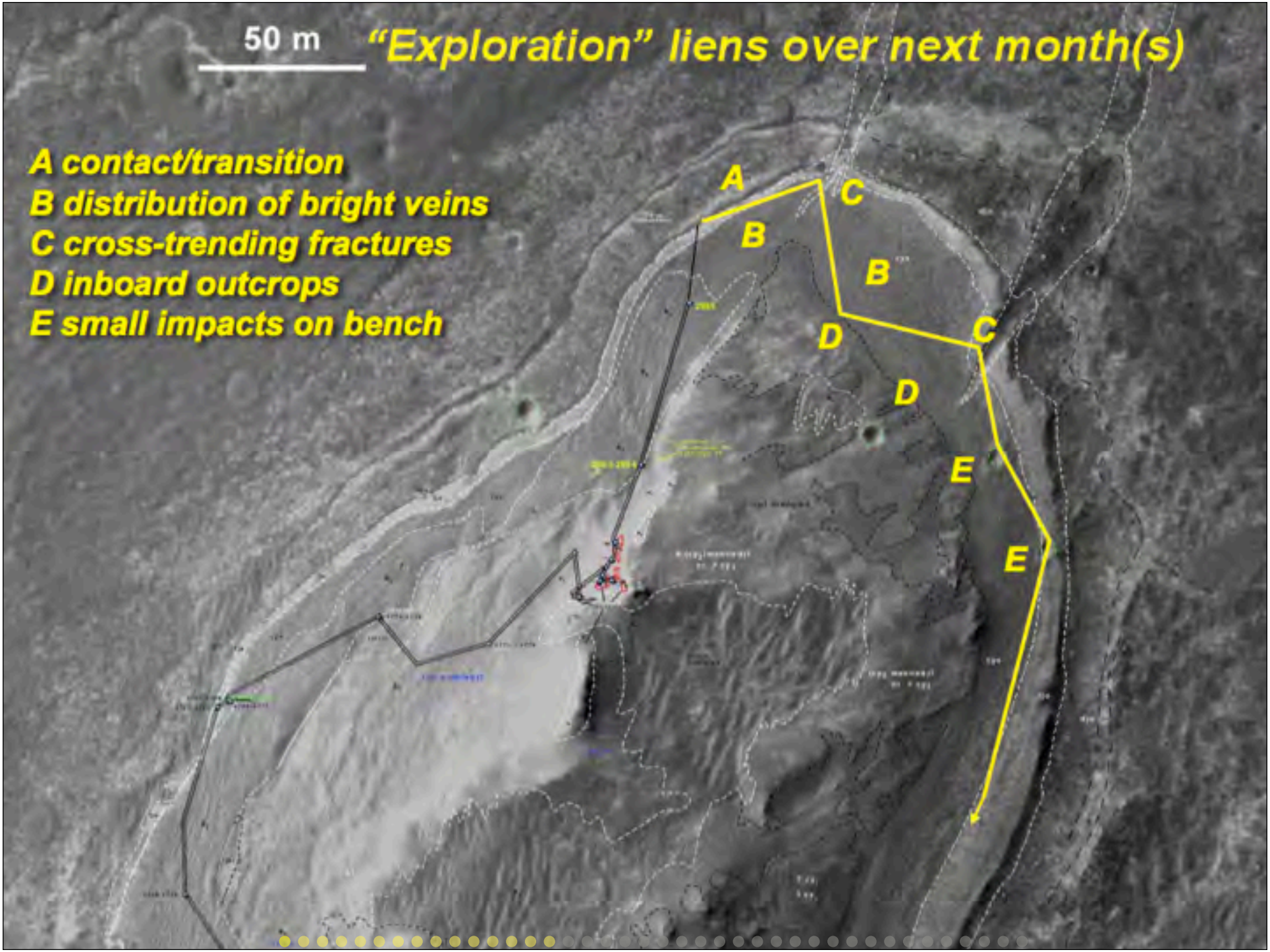

Sol 1
Eagle Crater
(Jan. '04)
"Endurance"
5 km
Left Victoria:
Sol 1679
(Oct. '08)
"Victoria"
Today:
Sol 3015
Clay mineral deposits
seen from orbit
"Endeavour"
more than 8.5 years
of operations on
Mars!
34.5 km (21.5 mi)
of driving
Endeavour
Crater
• 22 km diameter
• interesting water-
related minerals!

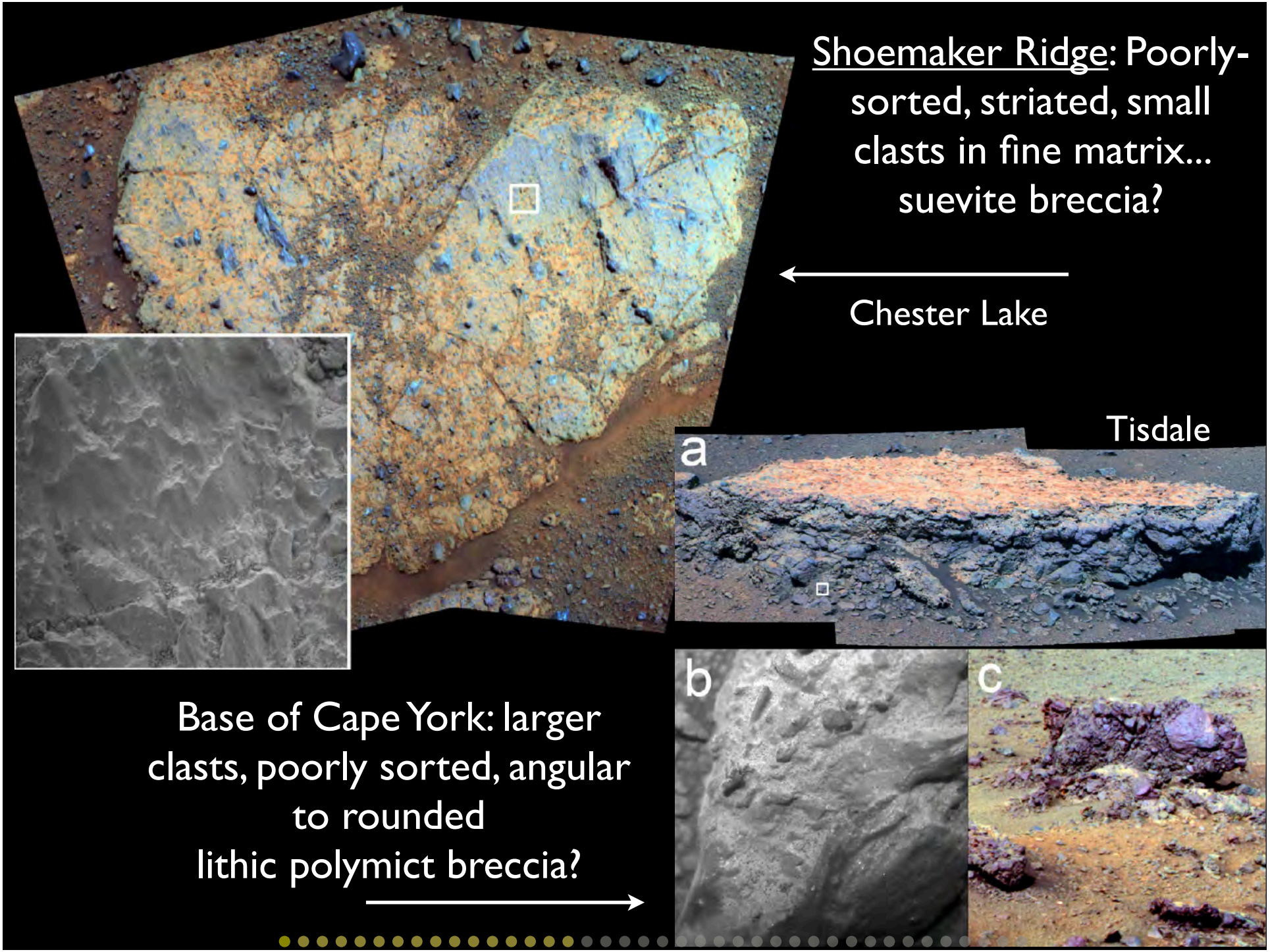


Exploring the rim of Endeavour crater...

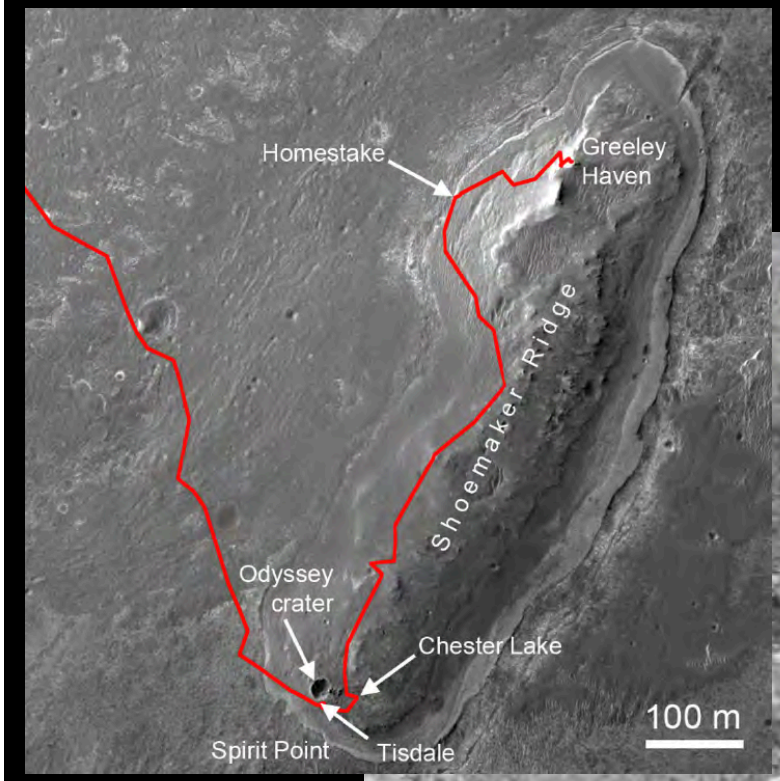
The strongest phyllosilicate signatures detected from orbit are on the SE (basinward) side of the crater rim deposits... but had to stay on NW slopes to maximize solar power!

...targets for the approaching spring and summer!


50 m
"Exploration" liens over next month(s)
A contact/transition
B distribution of bright veins
C cross-trending fractures
D inboard outcrops
E small impacts on bench
A
B
C
B
D
C
D
E
E


Shoemaker Ridge: Poorly-sorted, striated, small clasts in fine matrix... suevite breccia?
Chester Lake
Tisdale
a
b
c
Base of Cape York: larger clasts, poorly sorted, angular to rounded lithic polymict breccia?

Homestake vein

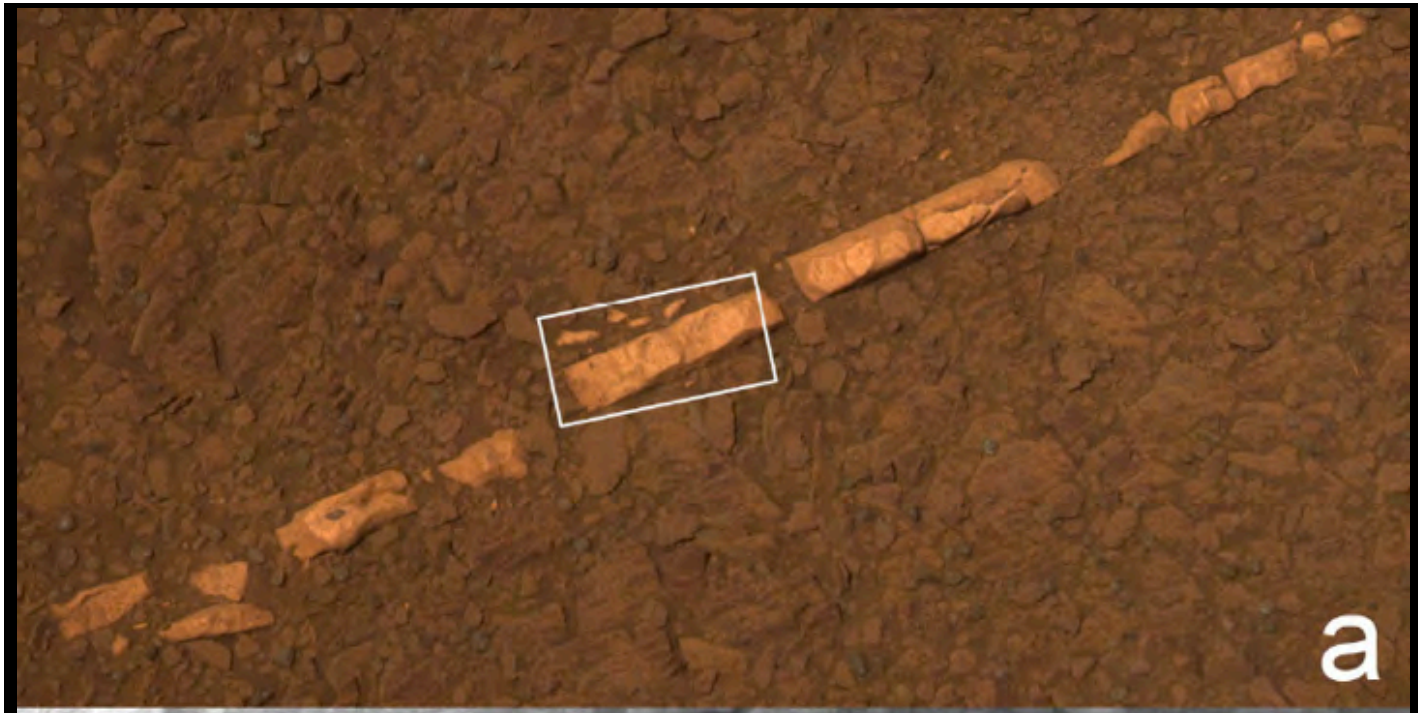


Triple crunch maneuver

Homestake

Drive to Winter Sites

Navcam sol 2773 Looking back at Homestake from north

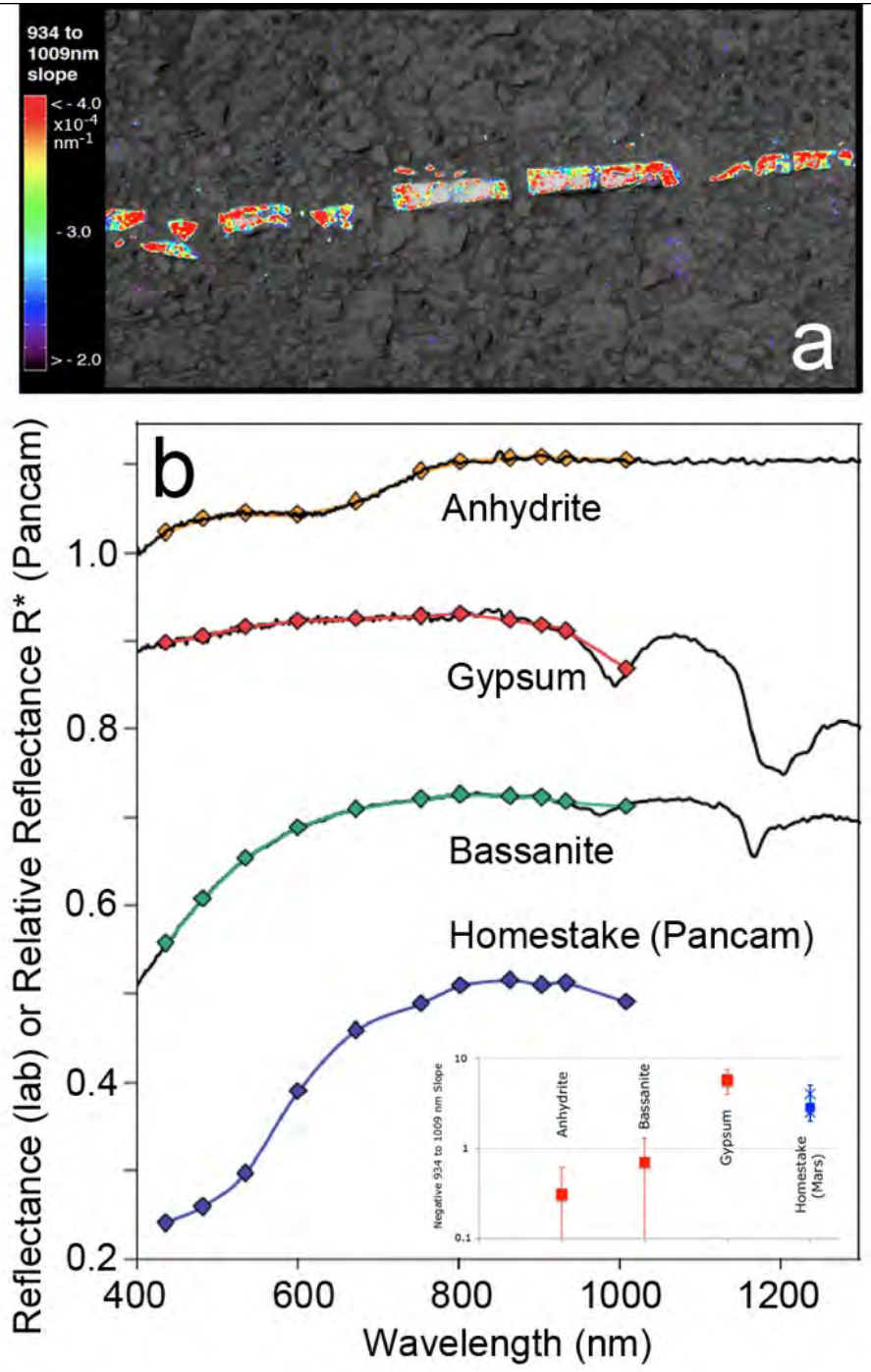


Homestake vein

Pancam
image width ~40 cm

MI (30 μm/pixel)
vein is ~1.5 cm wide

APXS data show
elevated S, Ca...
is this a calcium
sulfate vein?



Homestake vein lights up the Pancam "hydration index" defined by Rice et al (2010)

Spectral behavior near 1000 nm more consistent with gypsum ($CaSO_4 \cdot 2\ H_2O$) than anhydrite ($CaSO_4$) or bassanite ($CaSO_4 \cdot 0.5\ H_2O$)

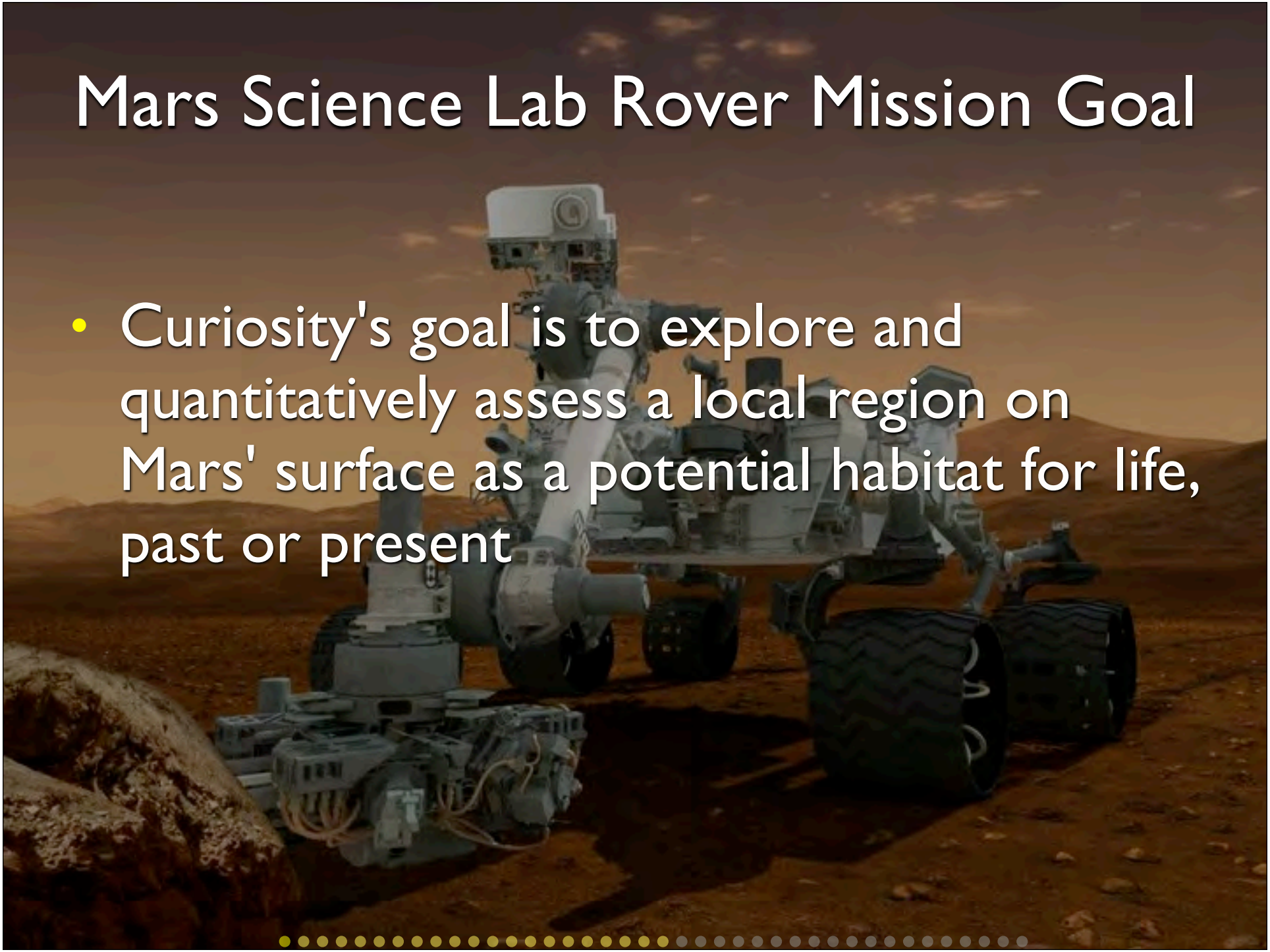
Gypsum interpretation consistent with APXS identification of high S, Ca in stoichiometric ratio consistent with $CaSO_4$

Squyres et al (2012), *Science*, 4 May

We parked on a north-facing slope at a Shoemaker ridge outcrop location called "Greeley Haven," riding out the rover's 5th Martian winter for about 5 Earth months...


Just released the Pancam 360° "Greeley Panorama"...

Mars Science Lab Rover Mission Goal



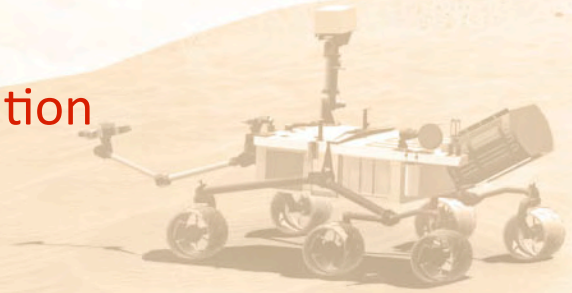
- Curiosity's goal is to explore and quantitatively assess a local region on Mars' surface as a potential habitat for life, past or present

Curiosity's Science Goals

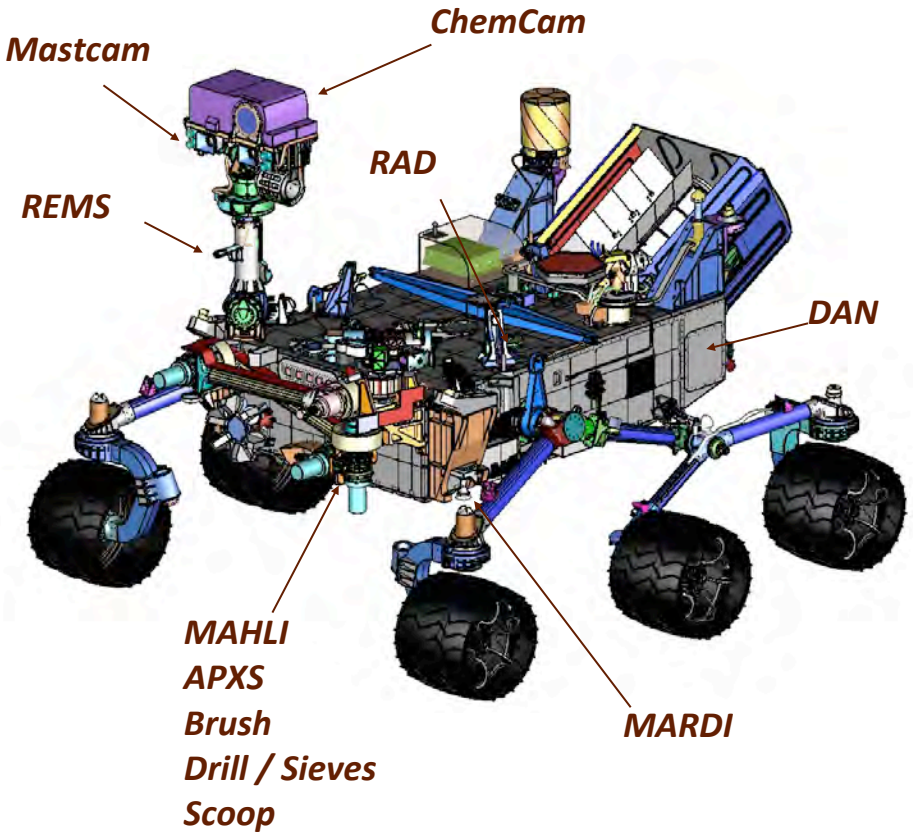
Curiosity's primary scientific goal is to explore and quantitatively assess a local region on Mars' surface as a potential habitat for life, past or present

Objectives include:

- Assessing the biological potential of the site by investigating any organic and inorganic compounds and the processes that might preserve them
- Characterizing geology and geochemistry, including chemical, mineralogical, and isotopic composition, and geological processes
- Investigating the role of water, atmospheric evolution, and modern weather/climate
- Characterizing the spectrum of surface radiation



MSL Science Payload



Wheel Base:	**2.8 m**
Height of Deck:	**1.1 m**
Ground Clearance:	**0.66 m**
Height of Mast:	**2.2 m**

REMOTE SENSING

Mastcam (M. Malin, MSSS) - Color and telephoto imaging, video, atmospheric opacity

ChemCam (R. Wiens, LANL/CNES) – Chemical composition; remote micro-imaging

CONTACT INSTRUMENTS (ARM)

MAHLI (K. Edgett, MSSS) – Hand-lens color imaging

APXS (R. Gellert, U. Guelph, Canada) - Chemical composition

ANALYTICAL LABORATORY (ROVER BODY)

SAM (P. Mahaffy, GSFC/CNES) - Chemical and isotopic composition, including organics

CheMin (D. Blake, ARC) - Mineralogy

ENVIRONMENTAL CHARACTERIZATION

MARDI (M. Malin, MSSS) - Descent imaging

REMS (J. Gómez-Elvira, CAB, Spain) - Meteorology / UV

RAD (D. Hassler, SwRI) - High-energy radiation

DAN (I. Mitrofanov, IKI, Russia) - Subsurface hydrogen

Science vs. Operational Goals

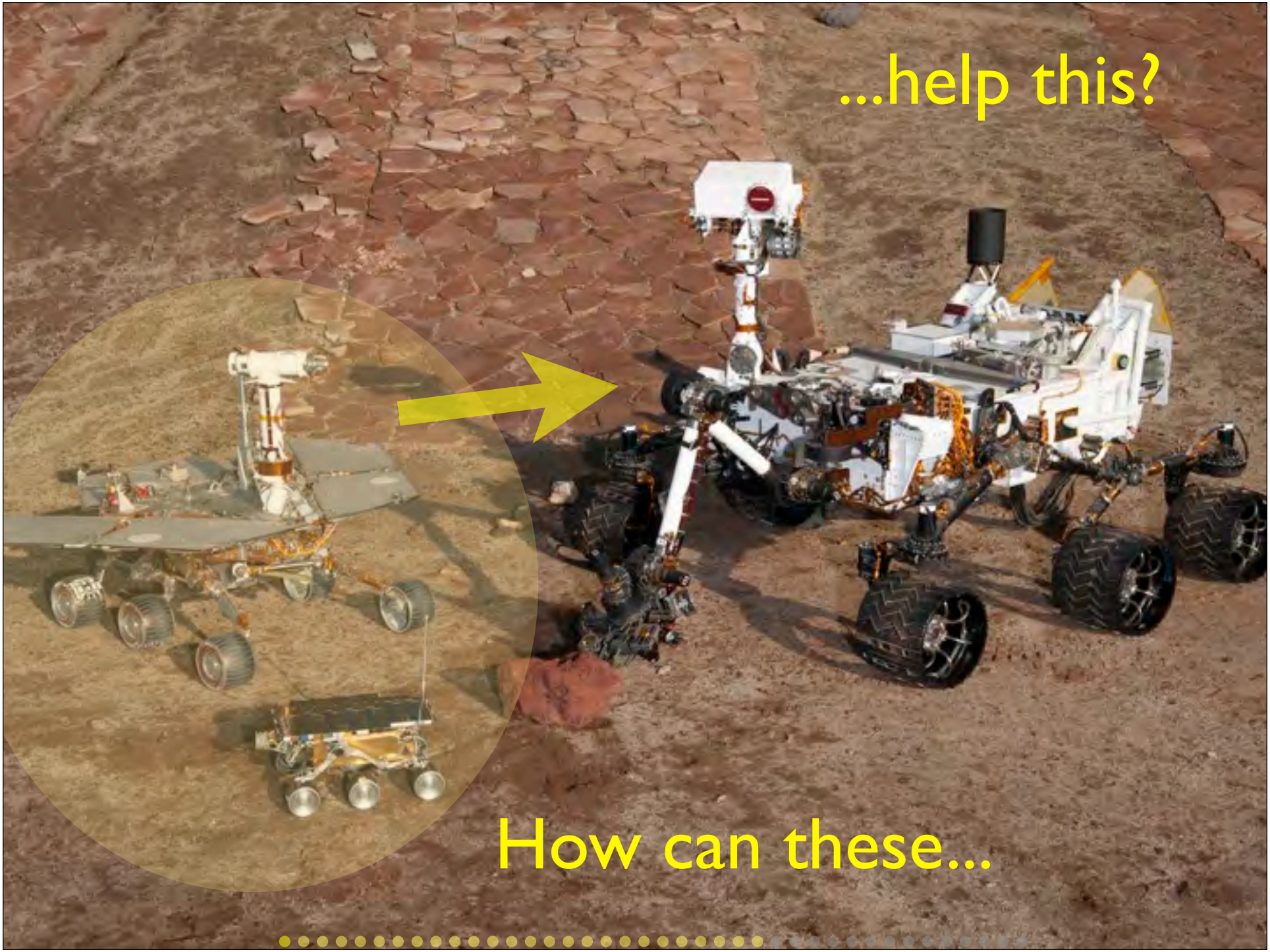
- Example MER Imaging Science Goals:

- Assess the high resolution morphology, topography, and geologic context of each rover's landing site
- Obtain color images to constrain the mineralogic, photometric, magnetic, and physical properties of surface materials
- Determine dust and aerosol opacity and physical properties from direct imaging of the Sun and sky.

Science vs. Operational Goals

- Example MER Imaging Operational Goals:

- Image the Sun for rover navigation
- Resolve wheel-sized hazards at 100 m distance to aid rover traverse decisions
- Provide stereo/topo data for driving and rover arm placement decisions
- Provide high-res, color imaging to help guide choice of *in situ* targets


...help this?
How can these...

Examples of Some Lessons Learned from MPF and MER During the Past 15 Years of Roving on Mars...

<u>From an Operational Perspective:</u>

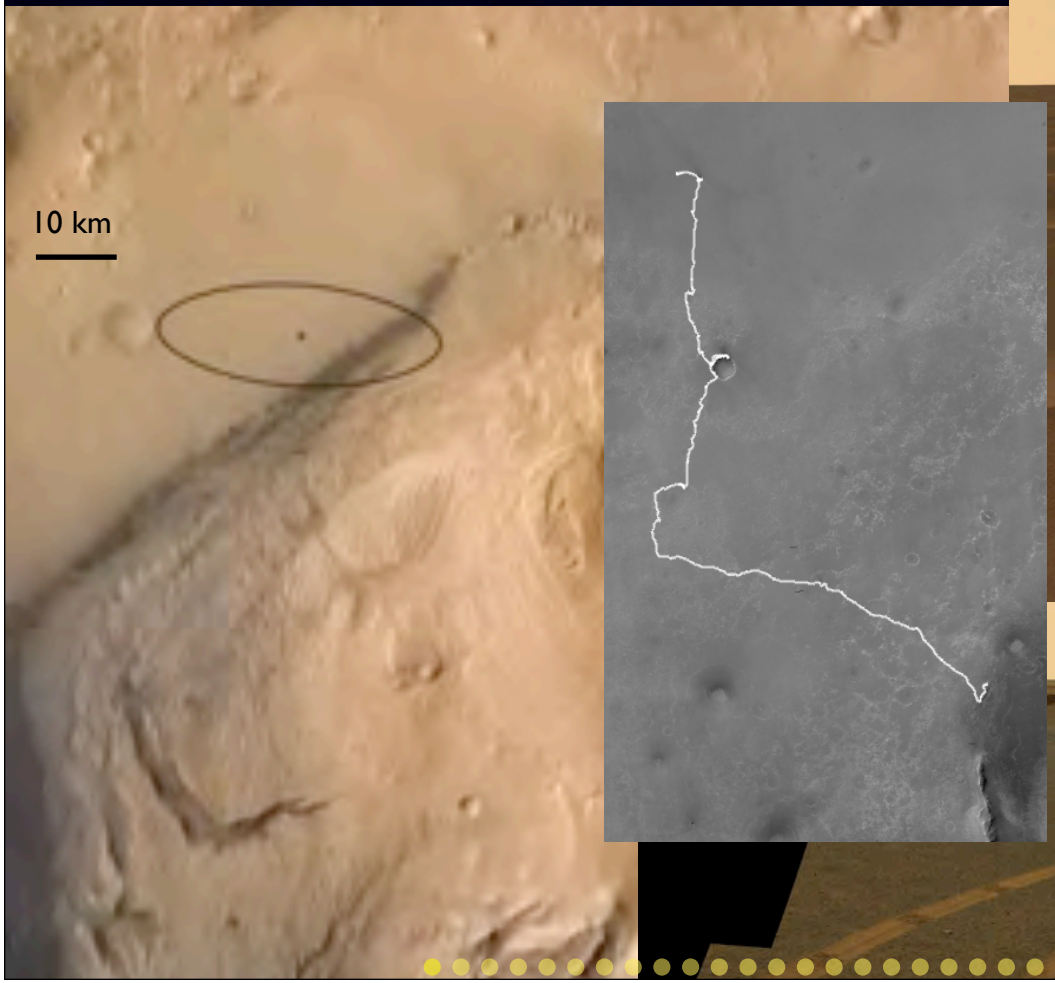
- Mobility, Mobility, Mobility...

Rover Rocks Rocker-Bogie

Examples of Some Lessons Learned from MPF and MER During the Past 15 Years of Roving on Mars...

From an Operational Perspective:

- Try to squeeze more out of Autonav...

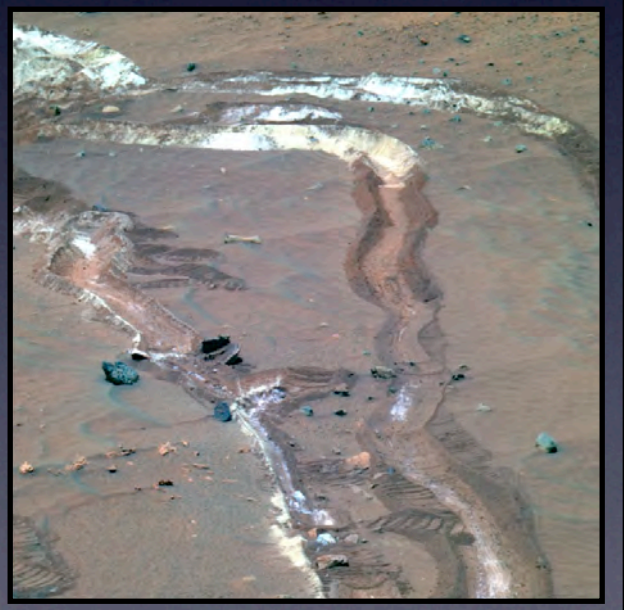


Examples of Some Lessons Learned from MPF and MER During the Past 15 Years of Roving on Mars...

From an Operational Perspective:

- Live Long and Prosper!

A.J.S. Rayl / The Planetary Society
http://planetary.org/msl/rover-wisdom/



Spirit sol 1096 Pancam false color

Examples of Some Lessons Learned from MPF and MER During the Past 15 Years of Roving on Mars...

From an Operational Perspective:

- Get the vehicle where the science is...

  ...carefully

Examples of Some Lessons Learned from MPF and MER During the Past 15 Years of Roving on Mars...

From an Operational Perspective:

- Without a RAT, use of the drill and the wheels will be critical to see through/below the dust!

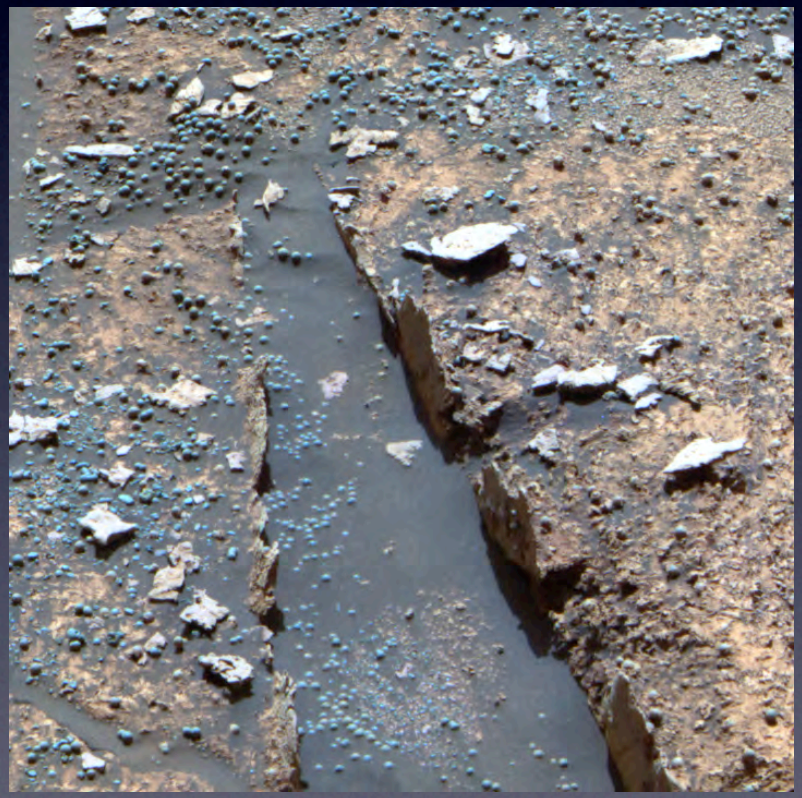
Spirit/Pancam sol 35, "Adirondack"

Opportunity/Pancam trench, sol 208

Examples of Some Lessons Learned from MPF and MER During the Past 15 Years of Roving on Mars...

From an Operational Perspective:

- Without remote mineral spectroscopy, samples of clays, sulfates, etc. might only be selectable via texture and color...



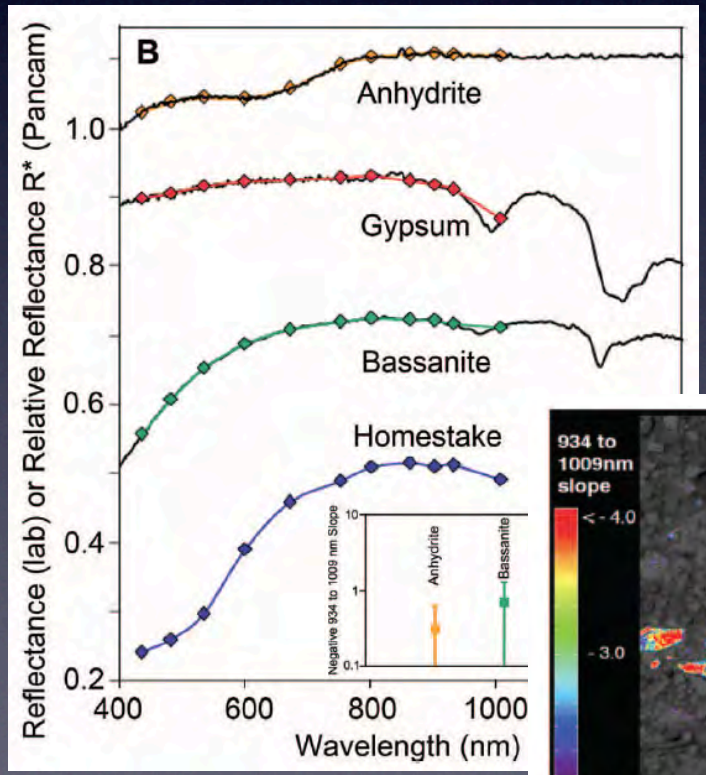
"Razorbacks"; MERB Sol 170, P2598

"Lemon Rind"; MERB Sol 561, P2591

Examples of Some Lessons Learned from MPF and MER During the Past 15 Years of Roving on Mars...

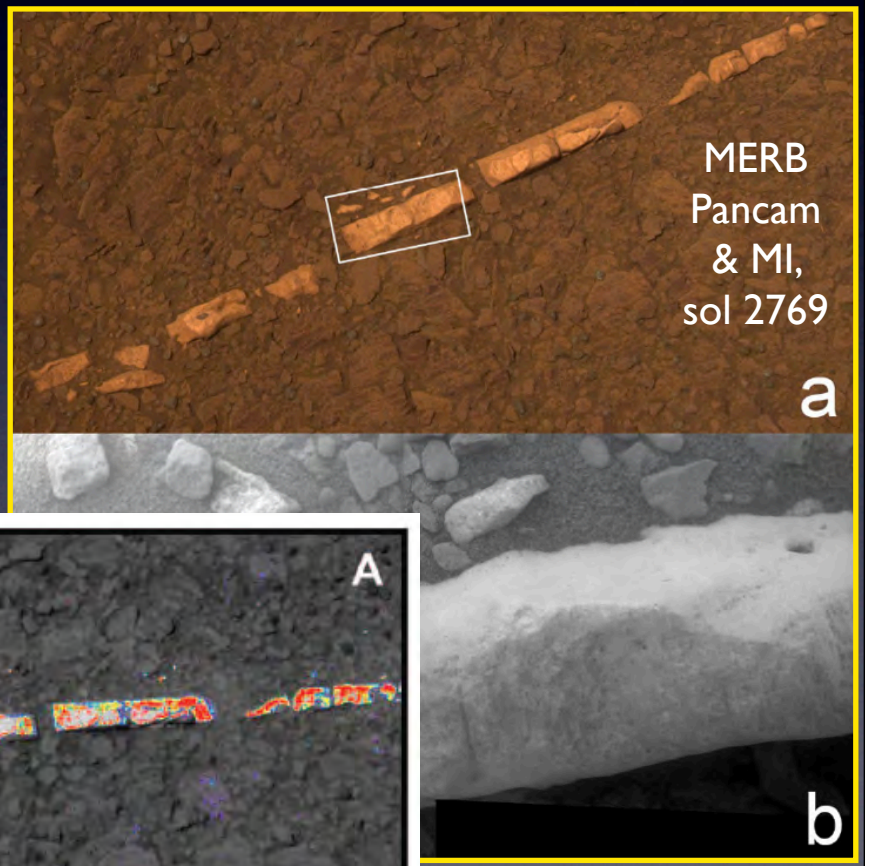
From an Operational Perspective:

- Without remote mineral spectroscopy, samples of clays, sulfates, etc. might only be selectable via texture and color...
  ...although Mastcam could help



Pancam "hydration index" map of gypsum vein

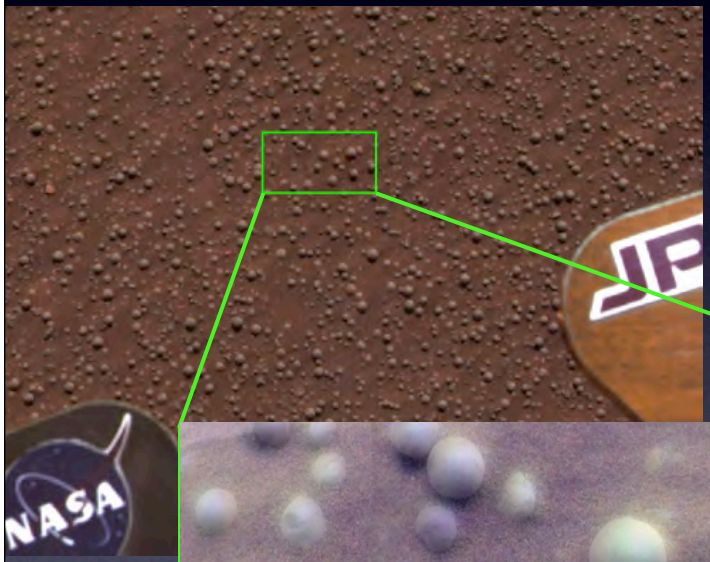
(Squyres *et al.* 2012)



Examples of Some Lessons Learned from MPF and MER During the Past 15 Years of Roving on Mars...

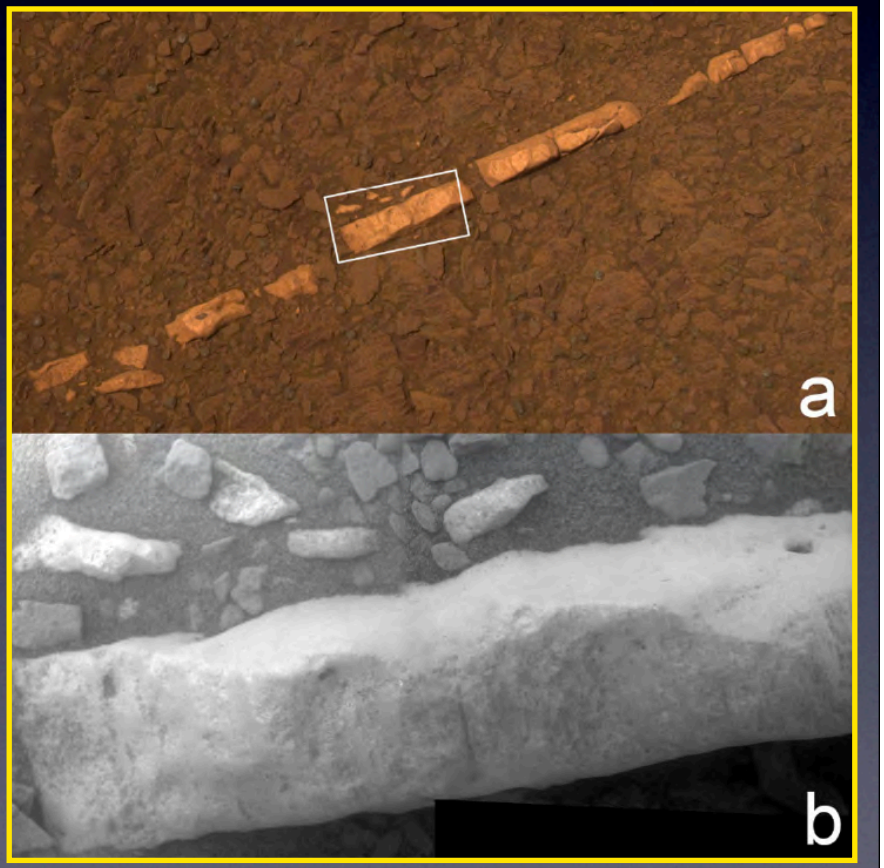
From a Science Perspective:

- Keep an open mind about the potential surface expression of different "expected" rocks and minerals...



MERB Pancam & MI, sol 14

MERB Pancam & MI, sol 2769



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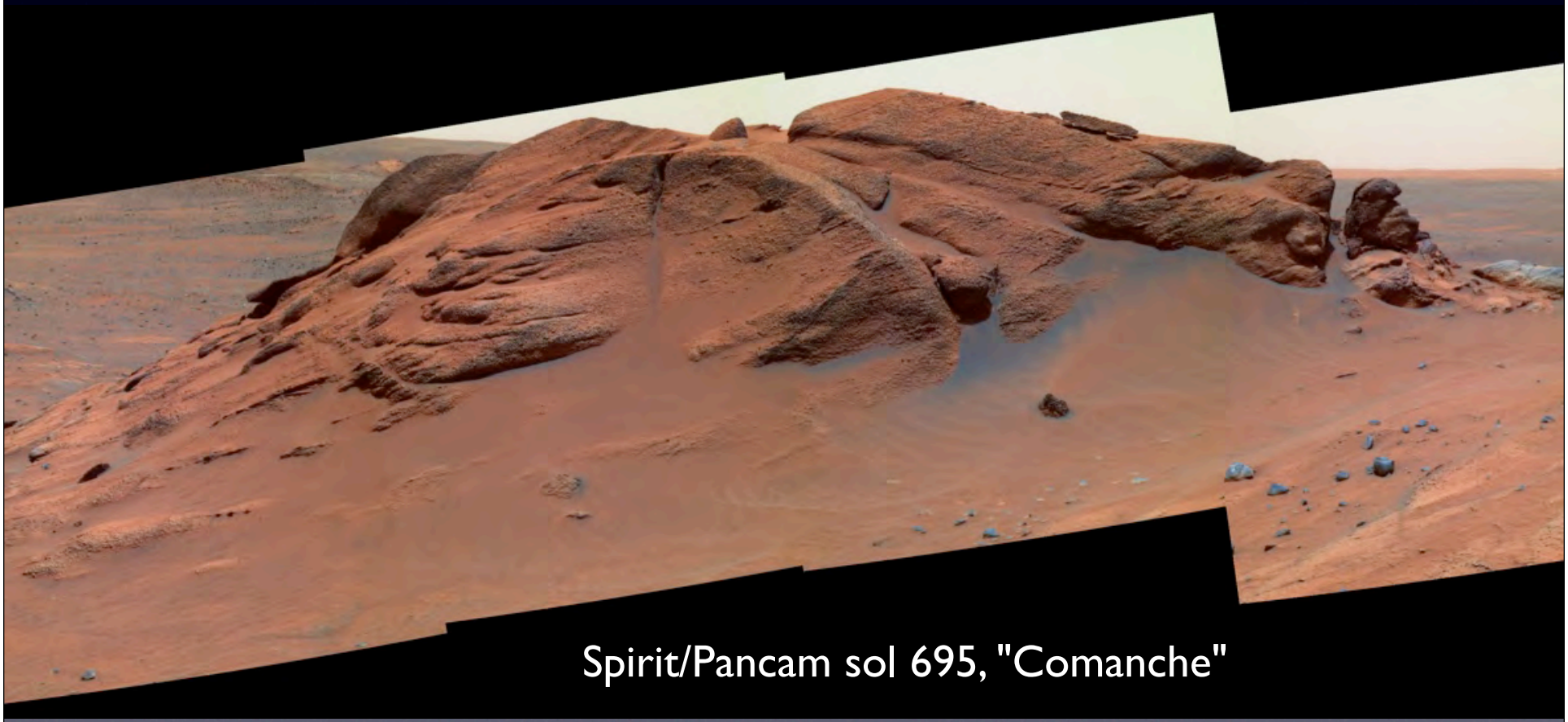
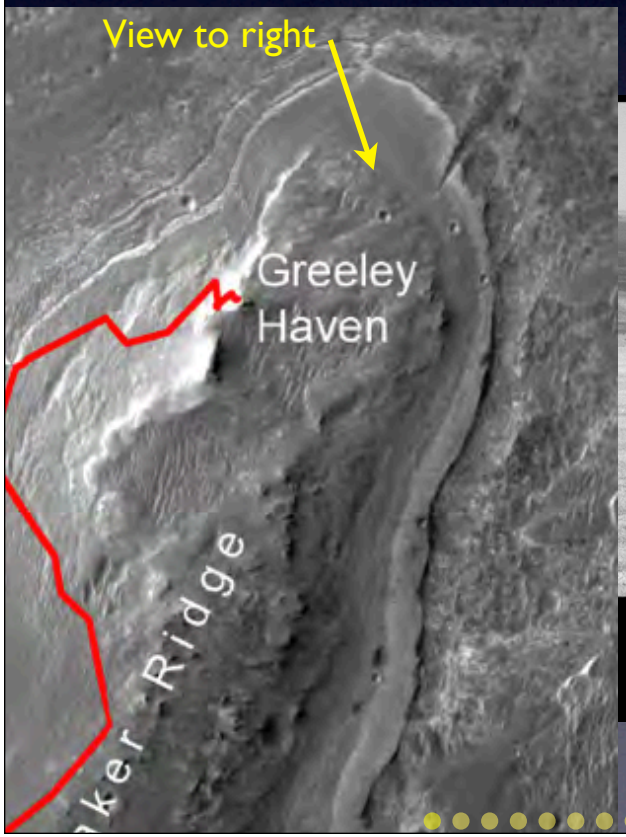


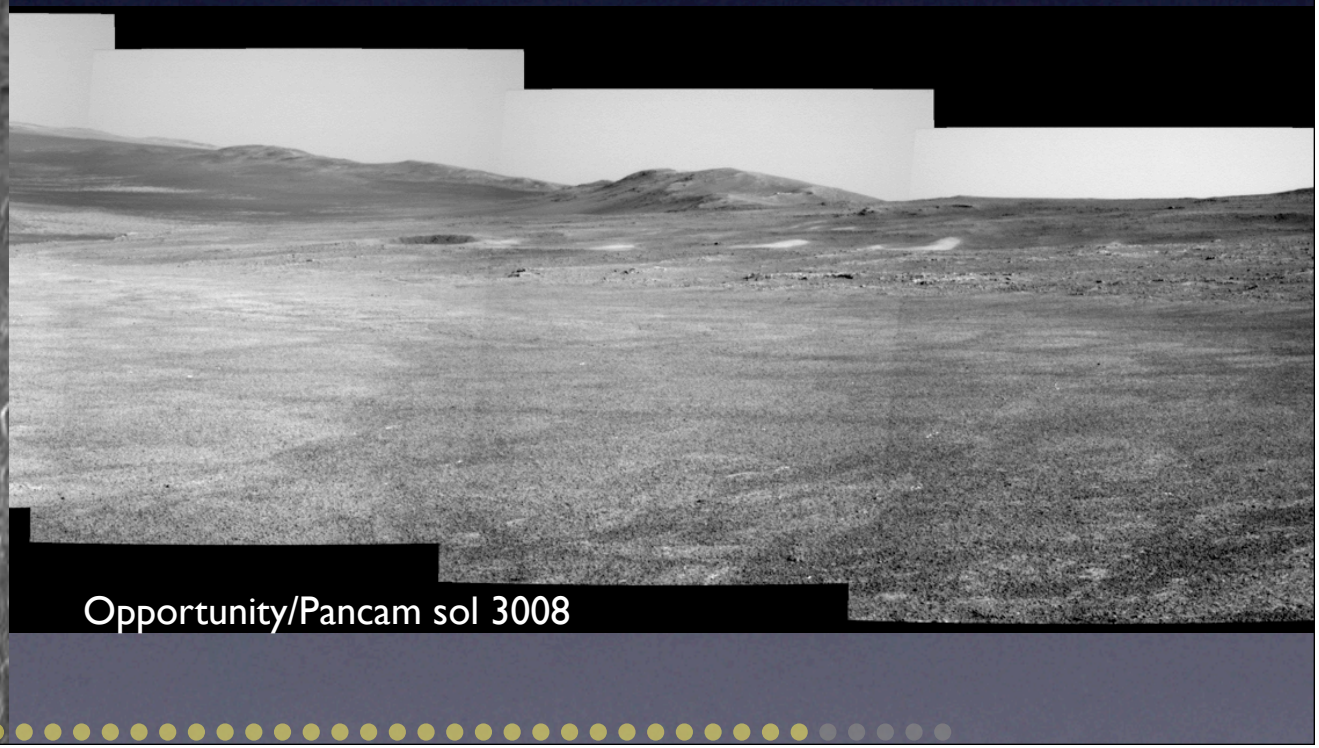
Spirit/Pancam sol 695, "Comanche"

Examples of Some Lessons Learned from MPF and MER During the Past 15 Years of Roving on Mars...

From a Science Perspective:

- Despite appearing clear in orbital/descent images, expect that key geologic contacts could be difficult to identify on the ground (just like in the field on Earth!).





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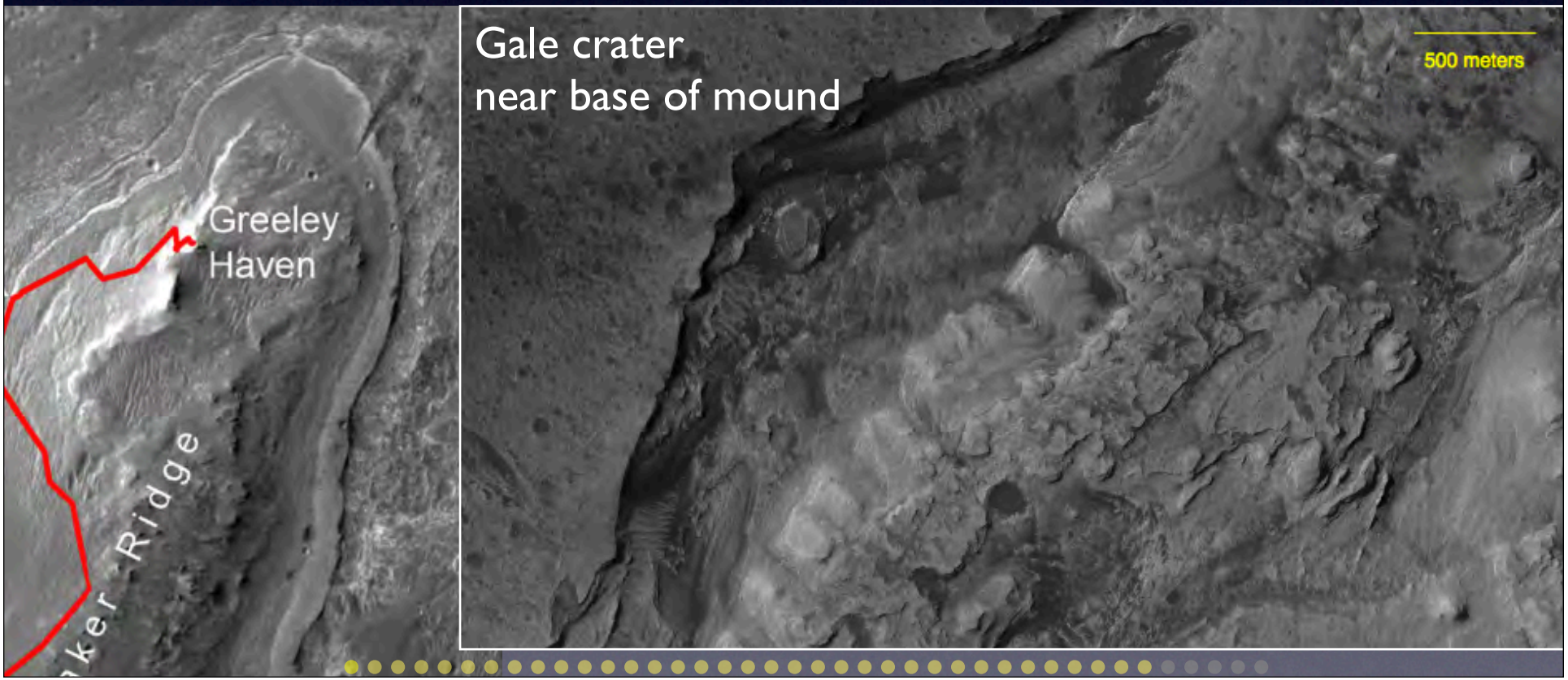
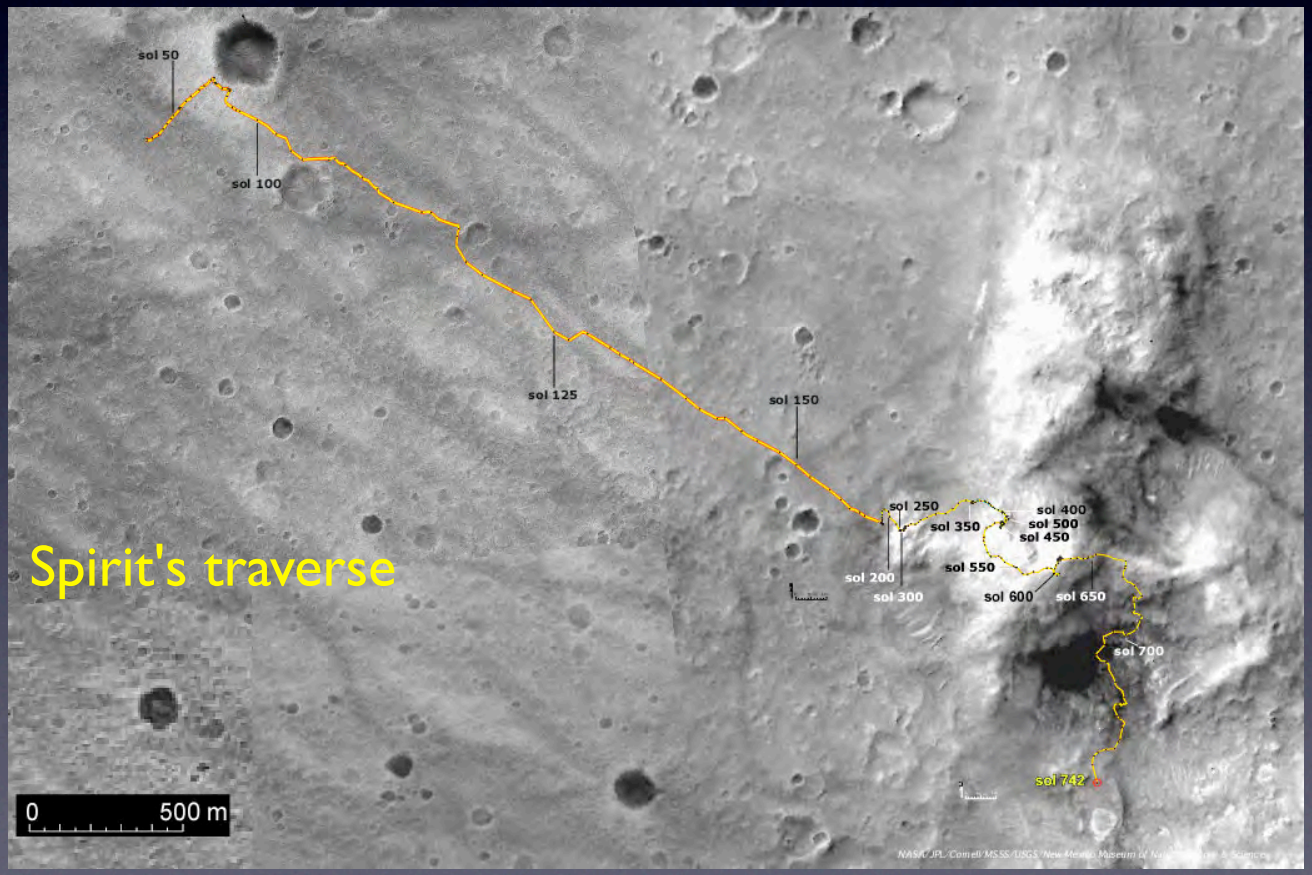


Examples of Some Lessons Learned from MPF and MER During the Past 15 Years of Roving on Mars...

From a Science Perspective:

- Despite the need to drive, drive, drive, resist the urge to just drive, drive, drive... (sample diversity well!)



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From a Science Perspective:

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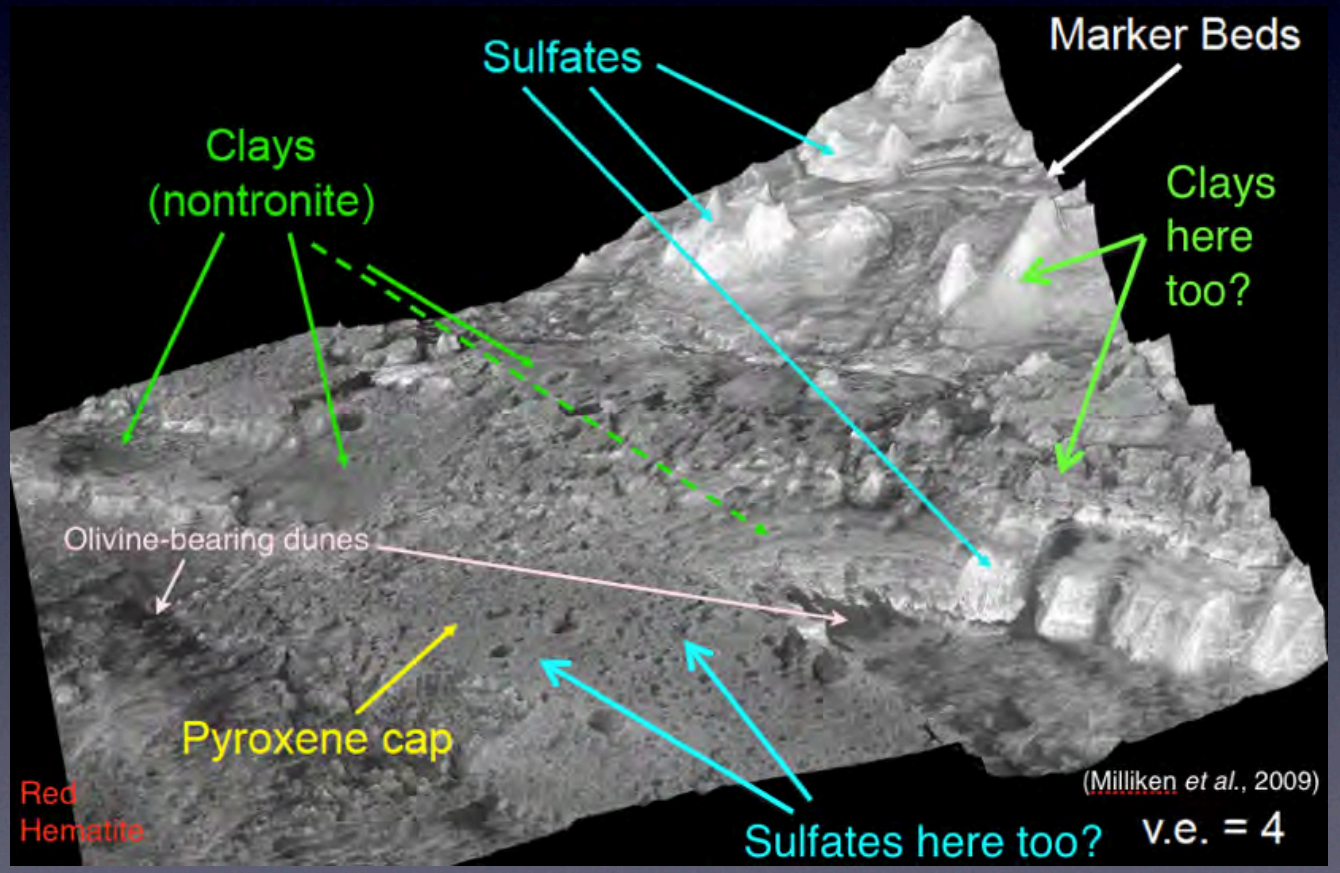
Possible MSL traverse area along edge of crater floor to Mt. Sharp transition...



Examples of Some Lessons Learned from MPF and MER During the Past 15 Years of Roving on Mars...

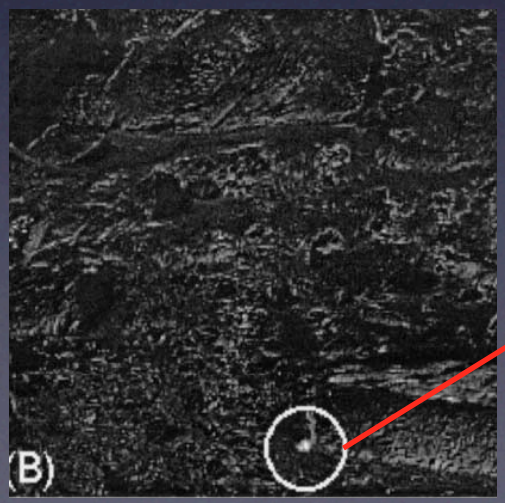
From a Science Perspective:

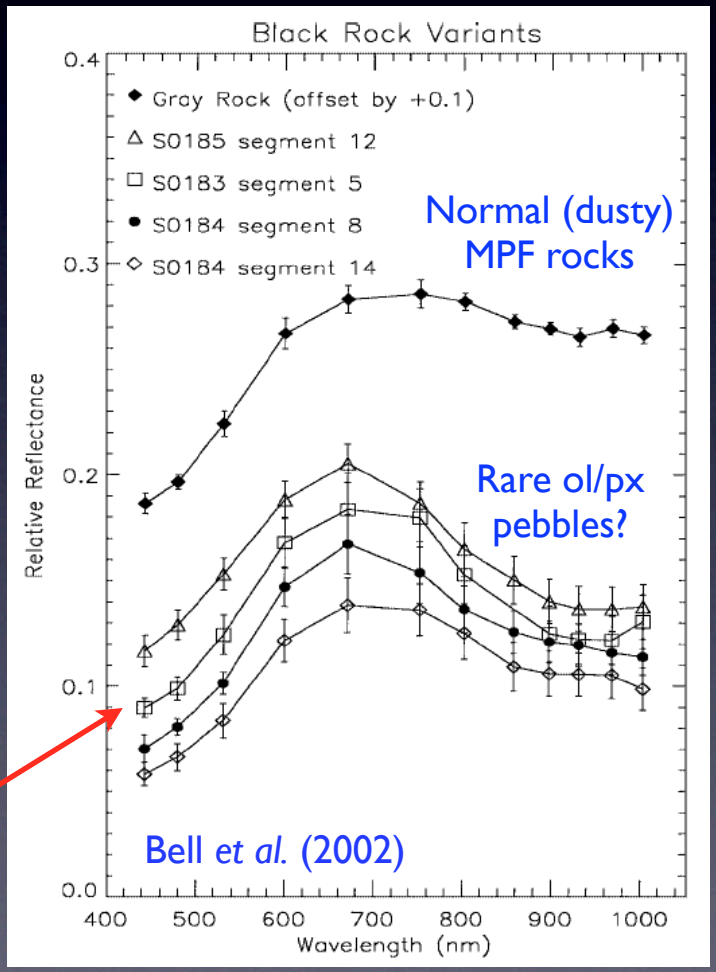
- Rapid/tactical science assessment will be critical!

Mars Pathfinder
"Super Pan" seq. S0184

An example that sticks in my craw of an example of and anomalous type of cobble/pebble that looked "normal" in RGB imaging but that turned out to have a deep Fe^{2+} absorption that we didn't identify until the mission was long over...

The only "clean" rocks at the site? APXS? Argh!

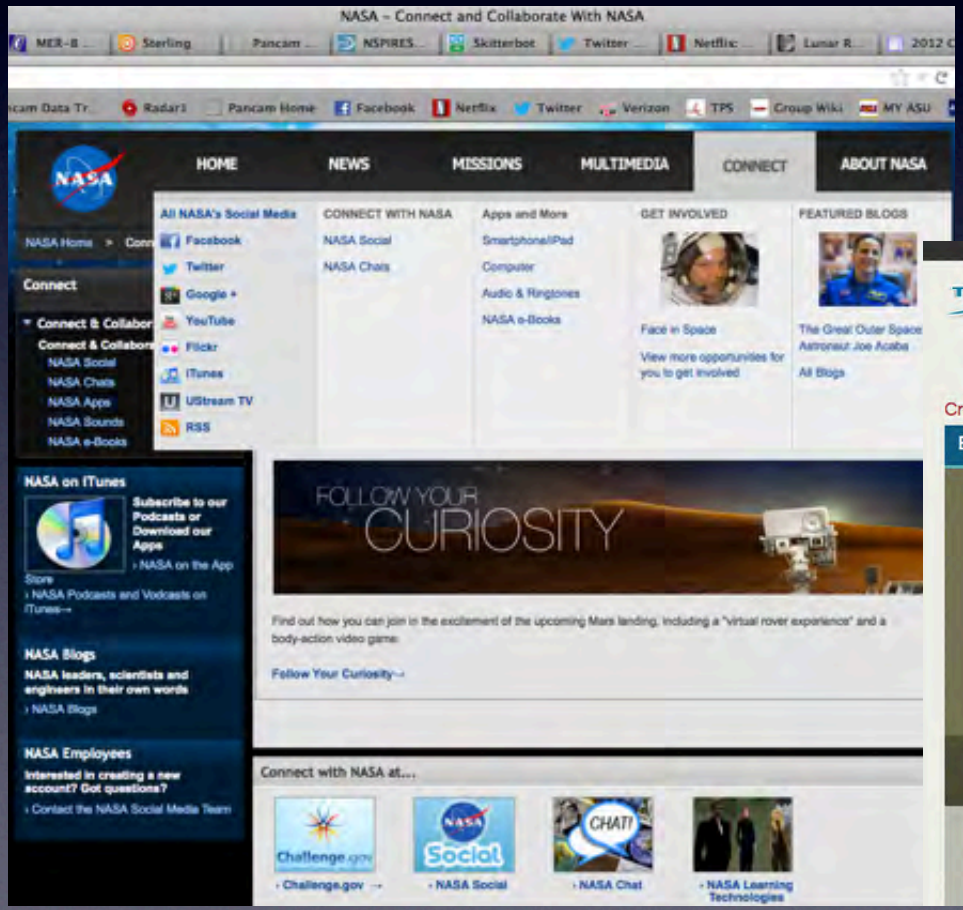




Examples of Some Lessons Learned from MPF and MER During the Past 15 Years of Roving on Mars...

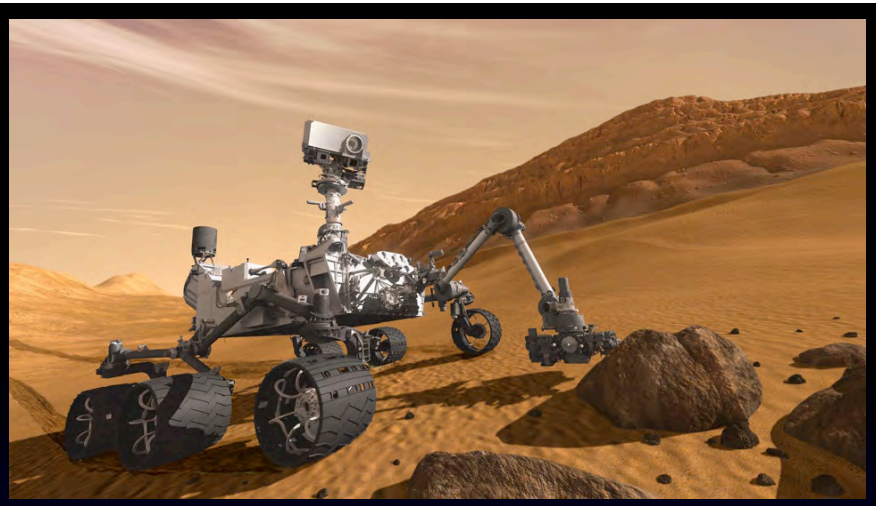
From an Education and Public Outreach Perspective:

- Make every possible effort to share the fruits (ripe as well as rotted) of this adventure with the public!



http://marsrovers.jpl.nasa.gov/gallery/all/
http://pancam.sese.asu.edu
http://www.planetary.org/blogs/emily-lakdawalla/
http://www.unmannedspaceflight.com/index.php?showforum=36

Summary: Lessons from MPF, MER



From an Operational Perspective:

- Mobility, Mobility, Mobility
- Try to squeeze more out of Autonav
- Live Long and Prosper!
- Get the vehicle where the science is
- Learn to use texture and color to identify sampling sites
- Learn to use the drill and wheels to see through the dust

From a Science Perspective:

- Rapid/tactical science assessment will be critical
- Expect that geologic contacts will be hard to identify
- Expect surprises in the surface expression of some minerals
- Be sure to sample the diversity, despite the urge to drive

And More!

From an Education and Public Outreach Perspective:

- Work hard to bring the public along for the ride

Follow along!

http://pancam.sese.asu.edu
http://marsrovers.jpl.nasa.gov
http://marsprogram.jpl.nasa.gov/msl
http://www.planetary.org

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